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(54) **VEHICLE DRIVING FORCE CONTROL DEVICE**

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B60W 40/101	(2012.01)
B60W 30/18	(2012.01)
B60W 40/103	(2012.01)

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CPC *B60W 40/101* (2013.01); *B60W 30/18172* (2013.01); *B60W 40/103* (2013.01); *B60W 2550/148* (2013.01)

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See application file for complete search history.

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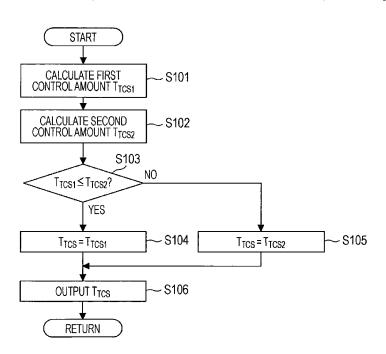JP 5-214974 8/1993

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(57) **ABSTRACT**

A vehicle driving force control device controls engine torque so as to correct driver's request-engine-torque with the torque-down amount by an engine control unit, the torque-down amount being set into the lower one of a first torque-down amount and a second torque-down amount by a control-amount setting unit, the first torque-down amount being calculated on the basis of a relation between a tire force generated on a tire and a maximum tire force which the tire is capable of exercising against a current road-surface by a first traction control unit, the second torque-down amount being calculated on the basis of a slip rate of the tire by a second traction control unit.
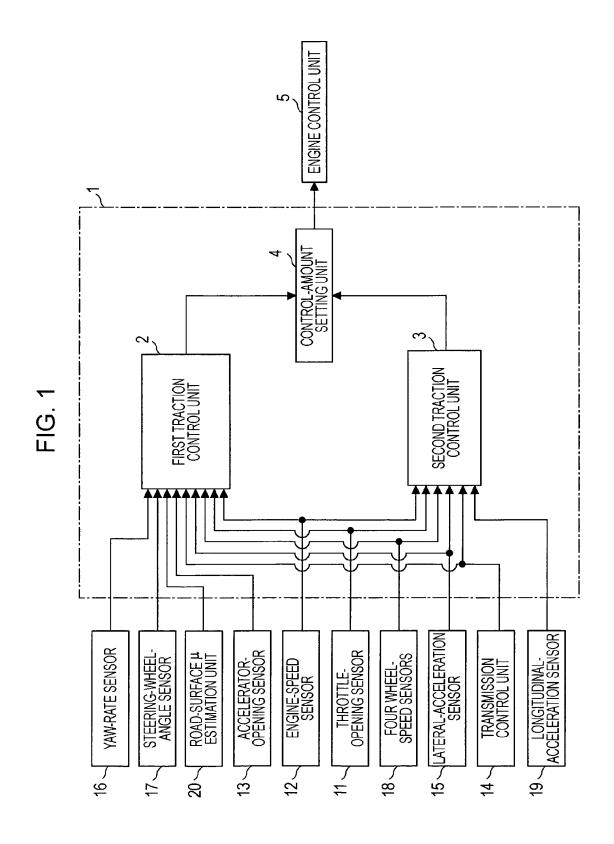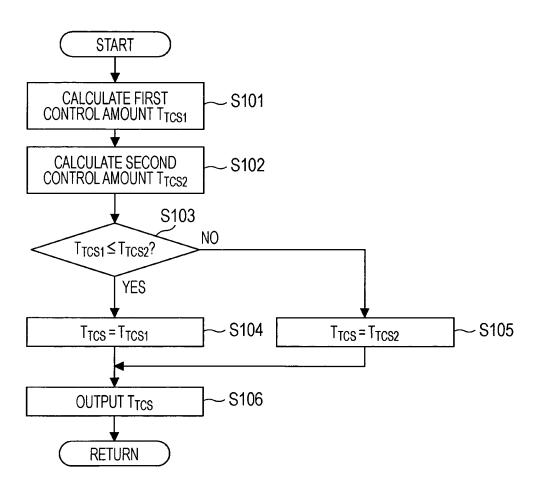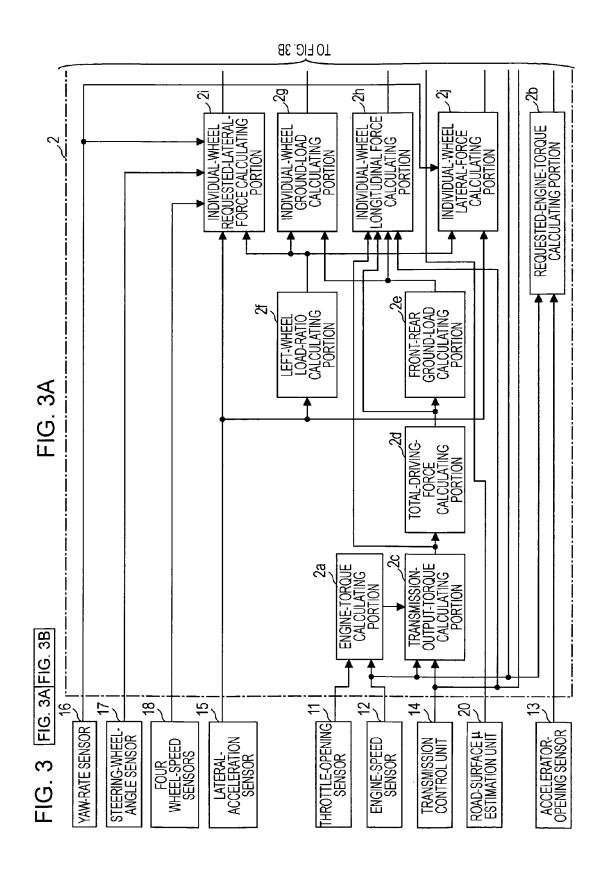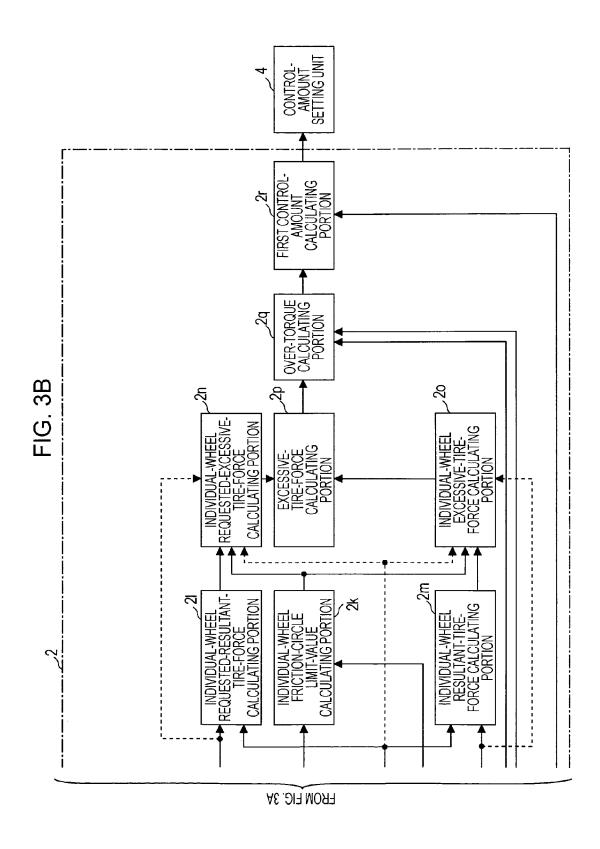
22 Claims, 13 Drawing Sheets

FIG. 1

FIG. 2

```
                    ┌──────────────┐
                    │    START     │
                    └──────┬───────┘
                           │
             ┌─────────────▼─────────────┐
             │   CALCULATE FIRST         │─── S101
             │ CONTROL AMOUNT T_TCS1     │
             └─────────────┬─────────────┘
                           │
             ┌─────────────▼─────────────┐
             │   CALCULATE SECOND        │─── S102
             │ CONTROL AMOUNT T_TCS2     │
             └─────────────┬─────────────┘
                           │         S103
                         ◆─▼────────◆          NO
                        ◆  T_TCS1 ≤ T_TCS2?  ◆──────────────┐
                         ◆──────────◆                       │
                           │ YES                            │
                           │                                │
             ┌─────────────▼─────────────┐    ┌─────────────▼─────────────┐
             │   T_TCS = T_TCS1          │    │   T_TCS = T_TCS2          │─── S105
             └─────────────┬─────────────┘    └─────────────┬─────────────┘
                        S104                                 │
                           │◄────────────────────────────────┘
             ┌─────────────▼─────────────┐
             │    OUTPUT T_TCS           │─── S106
             └─────────────┬─────────────┘
                           │
                    ┌──────▼───────┐
                    │   RETURN     │
                    └──────────────┘
```

Step S101: CALCULATE FIRST CONTROL AMOUNT T_{TCS1}

Step S102: CALCULATE SECOND CONTROL AMOUNT T_{TCS2}

Step S103: $T_{TCS1} \leq T_{TCS2}$?

Step S104: $T_{TCS} = T_{TCS1}$

Step S105: $T_{TCS} = T_{TCS2}$

Step S106: OUTPUT T_{TCS}

FIG. 3   FIG. 3A FIG. 3B

FIG. 3A

TO FIG. 3B

2

YAW-RATE SENSOR 16

STEERING-WHEEL-ANGLE SENSOR 17

FOUR WHEEL-SPEED SENSORS 18

LATERAL-ACCELERATION SENSOR 15

THROTTLE-OPENING SENSOR 11

ENGINE-SPEED SENSOR 12

TRANSMISSION CONTROL UNIT 14

ROAD-SURFACE μ ESTIMATION UNIT 20

ACCELERATOR-OPENING SENSOR 13

INDIVIDUAL-WHEEL REQUESTED-LATERAL-FORCE CALCULATING PORTION 2i

INDIVIDUAL-WHEEL GROUND-LOAD CALCULATING PORTION 2g

INDIVIDUAL-WHEEL LONGITUDINAL FORCE CALCULATING PORTION 2h

INDIVIDUAL-WHEEL LATERAL-FORCE CALCULATING PORTION 2j

REQUESTED-ENGINE-TORQUE CALCULATING PORTION 2b

LEFT-WHEEL LOAD-RATIO CALCULATING PORTION 2f

FRONT-REAR GROUND-LOAD CALCULATING PORTION 2e

TOTAL-DRIVING-FORCE CALCULATING PORTION 2d

ENGINE-TORQUE CALCULATING PORTION 2a

TRANSMISSION-OUTPUT-TORQUE CALCULATING PORTION 2c

FIG. 3B

CONTROL-AMOUNT SETTING UNIT — 4

FIRST CONTROL-AMOUNT CALCULATING PORTION — 2r

OVER-TORQUE CALCULATING PORTION — 2q

INDIVIDUAL-WHEEL REQUESTED-EXCESSIVE-TIRE-FORCE CALCULATING PORTION — 2n

EXCESSIVE-TIRE-FORCE CALCULATING PORTION — 2p

INDIVIDUAL-WHEEL EXCESSIVE-TIRE-FORCE CALCULATING PORTION — 2o

INDIVIDUAL-WHEEL REQUESTED-RESULTANT-TIRE-FORCE CALCULATING PORTION — 2l

INDIVIDUAL-WHEEL FRICTION-CIRCLE LIMIT-VALUE CALCULATING PORTION — 2k

INDIVIDUAL-WHEEL RESULTANT-TIRE-FORCE CALCULATING PORTION — 2m

2

FROM FIG. 3A

FIG. 4

```
                    ( START )
                        │
                        ▼
        ┌───────────────────────────────────┐
        │      READ REQUIRED PARAMETERS      │──── S201
        └───────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────────────┐
        │   CALCULATE ENGINE TORQUE $T_{eg}$   │──── S202
        └───────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────────────┐
        │ CALCULATE REQUESTED ENGINE TORQUE $T_{drv}$ │──── S203
        └───────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────────────┐
        │ CALCULATE TRANSMISSION OUTPUT TORQUE $T_t$ │──── S204
        └───────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────────────┐
        │   CALCULATE TOTAL DRIVING FORCE $F_x$  │──── S205
        └───────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────────────┐
        │ CALCULATE FRONT AND REAR GROUND LOADS $F_{zf}$ AND $F_{zr}$ │──── S206
        └───────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────────────┐
        │  CALCULATE LEFT-WHEEL LOAD-RATIO $WR\_l$  │──── S207
        └───────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────────────┐
        │ CALCULATE GROUND LOADS $F_{zf\_l}$, $F_{zf\_r}$, │──── S208
        │ $F_{zr\_l}$, AND $F_{zr\_r}$ OF INDIVIDUAL WHEELS │
        └───────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────────────┐
        │ CALCULATE LONGITUDINAL FORCES $F_{xf\_l}$, │──── S209
        │ $F_{xf\_r}$, $F_{xr\_l}$, AND $F_{xr\_r}$ OF INDIVIDUAL WHEELS │
        └───────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────────────┐
        │ CALCULATE REQUESTED LATERAL FORCES $F_{yf\_l\_FF}$, │──── S210
        │ $F_{yf\_r\_FF}$, $F_{yr\_l\_FF}$, AND $F_{yr\_r\_FF}$ OF INDIVIDUAL WHEELS │
        └───────────────────────────────────┘
                        │
                        ▼
        ┌───────────────────────────────────┐
        │ CALCULATE LATERAL FORCES $F_{yf\_l\_FB}$, $F_{yf\_r\_FB}$, │──── S211
        │ $F_{yr\_l\_FB}$, AND $F_{yr\_r\_FB}$ OF INDIVIDUAL WHEELS │
        └───────────────────────────────────┘
                        │
                        ▼
                      ( A )
```

FIG. 5

(A)

CALCULATE FRICTION-CIRCLE LIMIT-VALUES
μ_F_{zfl}, μ_F_{zfr}, μ_F_{zrl}, AND μ_F_{zrr} OF INDIVIDUAL WHEELS ⎯ S212

CALCULATE REQUESTED RESULTANT TIRE FORCES
F_{fl_FF}, F_{fr_FF}, F_{rl_FF}, AND F_{rr_FF} OF INDIVIDUAL WHEELS ⎯ S213

CALCULATE RESULTANT TIRE FORCES F_{fl_FB},
F_{fr_FB}, F_{rl_FB}, AND F_{rr_FB} OF INDIVIDUAL WHEELS ⎯ S214

CALCULATE REQUESTED EXCESSIVE TIRE FORCES ΔF_{fl_FF},
ΔF_{fr_FF}, ΔF_{rl_FF}, AND F_{rr_FF} OF INDIVIDUAL WHEELS ⎯ S215

CALCULATE EXCESSIVE TIRE FORCES ΔF_{fl_FB},
ΔF_{fr_FB}, ΔF_{rl_FB}, AND ΔF_{rr_FB} OF INDIVIDUAL WHEELS ⎯ S216

CALCULATE EXCESSIVE TIRE FORCE F_{over} ⎯ S217

CALCULATE OVER-TORQUE T_{over} ⎯ S218

CALCULATE AND OUTPUT FIRST CONTROL AMOUNT T_{TCS1} ⎯ S219

RETURN

FIG. 6

FIG. 7

FIG. 8

```
     ( ADDITIONAL YAW MOMENT CALCULATION ROUTINE )
                          │
                          ▼
        ┌─────────────────────────────────────┐
        │      CALCULATE VEHICLE SPEED V       │──── S301
        └─────────────────────────────────────┘
                          │
                          ▼
        ┌─────────────────────────────────────┐
        │   CALCULATE LATERAL-ACCELERATION/    │──── S302
        │   STEERING-WHEEL-ANGLE GAIN Gy       │
        └─────────────────────────────────────┘
                          │
                          ▼
        ┌─────────────────────────────────────┐
        │   CALCULATE LATERAL-ACCELERATION     │──── S303
        │   SATURATION COEFFICIENT Kμ          │
        └─────────────────────────────────────┘
                          │
                          ▼
        ┌─────────────────────────────────────┐
        │   CALCULATE LATERAL-ACCELERATION     │──── S304
        │   DEVIATION FEEDBACK GAIN Ky         │
        └─────────────────────────────────────┘
                          │
                          ▼
        ┌─────────────────────────────────────┐
        │ CALCULATE REFERENCE LATERAL ACCELERATION (d²yr/dt²) │──── S305
        └─────────────────────────────────────┘
                          │
                          ▼
        ┌─────────────────────────────────────┐
        │ CALCULATE LATERAL-ACCELERATION DEVIATION (d²ye/dt²) │──── S306
        └─────────────────────────────────────┘
                          │
                          ▼
        ┌─────────────────────────────────────┐
        │ CALCULATE YAW-RATE/STEERING-WHEEL-ANGLE GAIN Gγ │──── S307
        └─────────────────────────────────────┘
                          │
                          ▼
        ┌─────────────────────────────────────┐
        │   CALCULATE YAW-RATE FEEDBACK GAIN Kγ │──── S308
        └─────────────────────────────────────┘
                          │
                          ▼
        ┌─────────────────────────────────────┐
        │  CALCULATE VEHICLE-SPEED FEEDBACK GAIN Kv │──── S309
        └─────────────────────────────────────┘
                          │
                          ▼
        ┌─────────────────────────────────────┐
        │   CALCULATE ADDITIONAL YAW MOMENT Mzθ │──── S310
        └─────────────────────────────────────┘
                          │
                          ▼
                     ( RETURN )
```

Step S302: CALCULATE LATERAL-ACCELERATION/STEERING-WHEEL-ANGLE GAIN G_y

Step S303: CALCULATE LATERAL-ACCELERATION SATURATION COEFFICIENT $K\mu$

Step S304: CALCULATE LATERAL-ACCELERATION DEVIATION FEEDBACK GAIN K_y

Step S305: CALCULATE REFERENCE LATERAL ACCELERATION (d^2yr/dt^2)

Step S306: CALCULATE LATERAL-ACCELERATION DEVIATION (d^2ye/dt^2)

Step S307: CALCULATE YAW-RATE/STEERING-WHEEL-ANGLE GAIN G_γ

Step S308: CALCULATE YAW-RATE FEEDBACK GAIN K_γ

Step S309: CALCULATE VEHICLE-SPEED FEEDBACK GAIN K_v

Step S310: CALCULATE ADDITIONAL YAW MOMENT $M_z\theta$

FIG. 9A

FIG. 9B

FIG. 10

FIG. 11

FIG. 12

FIG. 13

FIG. 14

START

S401

$\lambda > L_{C1}$? — NO

YES S403

$\lambda > L_{C2}$? — NO

YES S405

$T_{TCS2} = T_{ED}$

S404

$T_{TCS2} = T_{EF}$

S402

$T_{TCS2} = T_{eg}$

RETURN

VEHICLE DRIVING FORCE CONTROL DEVICE

CROSS REFERENCES TO RELATED APPLICATIONS

The disclosure of Japanese Patent Application No. 2007-075635 filed on Mar. 22, 2007 including the specifications, drawings, and abstracts are incorporated by references herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a vehicle driving force control device for controlling a driving force to appropriately maintain a grip force of a vehicle wheel in various running conditions such as when a vehicle is in a starting mode, a straight running mode, or a turning mode.

2. Description of the Related Art

Various kinds of traction control devices for limiting the driving force to restrain a slipping of the vehicle wheel have been proposed and put to practical use.

For example, Japanese Unexamined Patent Application Publication No. 5-214974 discloses a technology where a slip rate of a drive wheel is calculated on the basis of the speed of the drive wheel and the speed of the vehicle body, and the engine output torque is reduced when the slip rate has exceeded a predetermined threshold value so as to perform feedback control on the throttle valve to restrain an excessive slipping of the drive wheel.

When a vehicle corners, a lateral force acting on a tire increases, whereas a permissible longitudinal driving force and the slip rate for maintaining a stable vehicle behavior decrease. Therefore, in a traction control device such as the one disclosed in Japanese Unexamined Patent Application Publication No. 5-214974, although it is necessary to detect a minute amount of slipping of the tire during cornering to stabilize the vehicle behavior, such detection is difficult since there is a limitation in the calculation accuracy for estimating the ground speed of the vehicle body. This makes it difficult to reduce the driving force to maintain the stability of the vehicle by determining a torque-down amount with high precision.

SUMMARY OF THE INVENTION

The present invention has been made under such circumstances, and it is an object of the present invention to provide a vehicle driving force control device that can control the driving force with high precision to improve the stability of the vehicle under all running conditions such as when the vehicle is undergoing a cornering mode, a straight running mode, or a starting mode.

The present invention provides a vehicle driving force control device that includes tire force estimating means configured to estimate a tire force generated on a tire, friction-circle limit-value estimating means configured to estimate a friction-circle limit-value as a maximum tire force which the tire is capable of exercising against a current road-surface, slip rate calculating means configured to calculate a slip rate of the tire, first torque-down amount calculating means configured to calculate a first torque-down amount on the basis of a relation between the tire force and the friction-circle limit-value, second torque-down amount calculating means configured to calculate a second torque-down amount on the basis of at least the slip rate, and driving-force setting means

configured to set a driving force of the vehicle in accordance with the first torque-down amount and the second torque-down amount.

According to the vehicle driving force control device of the present invention, the driving force can be controlled with high precision so that the stability of the vehicle can be improved under all running conditions such as when the vehicle is undergoing a cornering mode, a straight running mode, or a starting mode.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a functional block diagram of a driving force control device;

FIG. **2** is a flow chart of a driving force control program;

FIG. **3** is a functional block diagram of a first traction control unit;

FIG. **4** is a flow chart of a first control amount calculation program;

FIG. **5** is a flow chart continuing from that in FIG. **4**;

FIG. **6** illustrates an example of an engine torque set on the basis of an engine speed and a throttle opening;

FIG. **7** illustrates an example of a relationship between an accelerator opening and a throttle opening for generating a requested engine torque;

FIG. **8** is a flow chart of an additional-yaw-moment calculation routine;

FIGS. **9**A and **9**B illustrate a lateral-acceleration saturation coefficient;

FIG. **10** shows a characteristic map of a vehicle-speed feedback gain;

FIG. **11** illustrates a difference in additional yaw moment value between a high μ road and a low μ road;

FIG. **12** illustrates an excessive tire force that is to be minimized;

FIG. **13** is a functional block diagram of a second traction control unit; and

FIG. **14** is a flow chart of a second control amount calculation program.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will now be described with reference to the drawings.

FIGS. **1** to **14** illustrate an embodiment of the present invention. In this embodiment, the vehicle is directed to a four-wheel-drive vehicle equipped with a center differential as an example. In this vehicle, a limited-slip differential clutch (tightening torque T_{LSD}) allows a longitudinal driving-force distribution to be adjustable on the basis of a base torque distribution R_{f_cd} by the center differential.

Referring to FIG. **1**, reference numeral **1** denotes a vehicle driving force control device installed in a vehicle and for appropriately controlling a driving force. The driving force control device **1** is connected to a throttle-opening sensor **11**, an engine-speed sensor **12**, an accelerator-opening sensor **13**, a transmission control unit **14**, a lateral-acceleration sensor **15**, a yaw-rate sensor **16**, a steering-wheel-angle sensor **17**, wheel-speed sensors **18** for individual wheels, a longitudinal-acceleration sensor **19**, and a road-surface μ estimation unit **20**, and receives therefrom signals indicating a throttle opening θ_{th}, an engine speed N_e, an accelerator opening θ_{ACC}, a main transmission gear ratio i, a turbine speed N_t of a torque converter, a tightening torque T_{LSD} of a limited-slip differential clutch, a lateral acceleration (d^2y/dt^2), a yaw rate γ, a steering-wheel angle θ_H, wheel speeds ω_{fl}, ω_{fr}, ω_{rl}, and ω_{rr} of

the individual wheels (the additional characters "fl", "fr", "rl", and "rr" respectively indicating a front left wheel, a front right wheel, a rear left wheel, and a rear right wheel), a longitudinal acceleration (d^2x/dt^2), and a road-surface friction coefficient μ.

Based on these input signals, the driving force control device **1** calculates an appropriate driving force value in accordance with a driving force control program to be described hereinafter, and outputs the driving force value to an engine control unit **5**. The engine control unit **5** outputs a control signal to a throttle control unit (not shown) so as to allow a motor to be driven, whereby a throttle valve is actuated.

As shown in FIG. **1**, the driving force control device **1** mainly includes a first traction control unit **2**, a second traction control unit **3**, and a control-amount setting unit **4**.

The first traction control unit **2** is provided as first torque-down amount calculating means. The first traction control unit **2** is connected to the throttle-opening sensor **11**, the engine-speed sensor **12**, the accelerator-opening sensor **13**, the transmission control unit **14**, the lateral-acceleration sensor **15**, the yaw-rate sensor **16**, the steering-wheel-angle sensor **17**, the wheel-speed sensors **18** for the individual wheels, and the road-surface μ estimation unit **20**, and receives therefrom signals indicating a throttle opening θ_{th}, an engine speed N_e, an accelerator opening θ_{ACC}, a main transmission gear ratio i, a turbine speed N_t of the torque converter, a tightening torque T_{LSD} of the limited-slip differential clutch, a lateral acceleration (d^2y/dt^2), a yaw rate γ, a steering-wheel angle θ_H, wheel speeds ω_{fl}, ω_{fr}, ω_{rl}, and ω_{rr} of the individual wheels (the additional characters "fl", "fr", "rl", and "rr" respectively indicating a front left wheel, a front right wheel, a rear left wheel, and a rear right wheel), and a road-surface friction coefficient μ.

Referring to FIG. **3**, the first traction control unit **2** mainly includes an engine-torque calculating portion **2a**, a requested-engine-torque calculating portion **2b**, a transmission-output-torque calculating portion **2c**, a total-driving-force calculating portion **2d**, a front-rear ground-load calculating portion **2e**, a left-wheel load-ratio calculating portion **2f**, an individual-wheel ground-load calculating portion **2g**, an individual-wheel longitudinal-force calculating portion **2h**, an individual-wheel requested-lateral-force calculating portion **2i**, an individual-wheel lateral-force calculating portion **2j**, an individual-wheel friction-circle limit-value calculating portion **2k**, an individual-wheel requested-resultant-tire-force calculating portion **2l**, an individual-wheel resultant-tire-force calculating portion **2m**, an individual-wheel requested-excessive-tire-force calculating portion **2n**, an individual-wheel excessive-tire-force calculating portion **2o**, an excessive-tire-force calculating portion **2p**, an over-torque calculating portion **2q**, and a first control-amount calculating portion **2r**.

The engine-torque calculating portion **2a** receives a throttle opening θ_{th} from the throttle-opening sensor **11** and an engine speed N_e from the engine-speed sensor **12**. The engine-torque calculating portion **2a** refers to a map (such as the map shown in FIG. **6**) preliminarily set based on engine characteristics so as to determine an engine torque T_{eg} currently being generated. The engine-torque calculating portion **2a** then outputs the determined engine torque T_{eg} to the transmission-output-torque calculating portion **2c**. The engine torque T_{eg} may alternatively be read from the engine control unit **5**.

The requested-engine-torque calculating portion **2b** receives an accelerator opening θ_{ACC} from the accelerator-opening sensor **13**. The requested-engine-torque calculating portion **2b** refers to a preliminarily set map (such as the map

of a relationship between an accelerator opening θ_{ACC} and a throttle opening θ_{th} shown in FIG. **7**) so as to determine the throttle opening θ_{th}, and determine the engine torque T_{eg} based on the determined throttle opening θ_{th} from the aforementioned map shown in FIG. **6**. The requested-engine-torque calculating portion **2b** then outputs the determined engine torque T_{eg} as a requested engine torque T_{drv}. The requested engine torque T_{drv} may alternatively be determined from a preliminarily set map associated with an accelerator opening θ_{ACC}, or be read from the engine control unit **5**.

The transmission-output-torque calculating portion **2c** receives the engine speed N_e from the engine-speed sensor **12**, a main transmission gear ratio i and a turbine speed N_t of a torque converter from the transmission control unit **14**, and the engine torque T_{eg} from the engine-torque calculating portion **21a**.

The transmission-output-torque calculating portion **2c** calculates a transmission output torque T_t from, for example, the following expression (1) and outputs the calculated transmission output torque T_t to the total-driving-force calculating portion **2d** and the individual-wheel longitudinal-force calculating portion **2h**.

$$T_t = T_{eg} \cdot t \cdot i \tag{1}$$

In this case, t indicates a torque ratio of the torque converter and is determined by referring to a preliminarily set map indicating a relationship between a rotational speed ratio e ($=N_t/N_e$) of the torque converter and a torque ratio of the torque converter.

The total-driving-force calculating portion **2d** receives the transmission output torque T_t from the transmission-output-torque calculating portion **2c**.

The total-driving-force calculating portion **2d** calculates a total driving force F_x from, for example, the following expression (2) and outputs the calculated total driving force F_x to the front-rear ground-load calculating portion **2e** and the individual-wheel longitudinal-force calculating portion **2h**.

$$F_x = T_t \cdot \eta \cdot i_f / R_t \tag{2}$$

In this case, η indicates a transmission efficiency of a driving system, i_f indicates a final gear ratio, and R_t indicates a tire radius.

The front-rear ground-load calculating portion **2e** receives the total driving force F_x from the total-driving-force calculating portion **2d**. The front-rear ground-load calculating portion **2e** then calculates a front-wheel ground load F_{zf} from the following expression (3) and outputs the calculated front-wheel ground load F_{zf} to the individual-wheel ground-load calculating portion **2g** and the individual-wheel longitudinal-force calculating portion **2h**. In addition, the front-rear ground-load calculating portion **2e** calculates a rear-wheel ground load F_{zr} from the following expression (4) and outputs the calculated rear-wheel ground load F_{zr} to the individual-wheel ground-load calculating portion **2g**.

$$F_{zf} = W_f - ((m \cdot (d^2x/dt^2) \cdot h)/L) \tag{3}$$

$$F_{zr} = W - F_{zf} \tag{4}$$

In this case, W_f indicates a front-wheel static load, m indicates a vehicle mass, (d^2x/dt^2) indicates a longitudinal acceleration ($=F_x/m$), h indicates the height of gravitational center, L indicates a wheel base, and W indicates a vehicle weight (gravitational force) ($=m \cdot G$; G being a gravitational acceleration).

The left-wheel load-ratio calculating portion **2f** receives a lateral acceleration (d^2y/dt^2) from the lateral-acceleration sensor **15**. The left-wheel load-ratio calculating portion **2f** calculates a left-wheel load-ratio WR_l from the following

5   6

expression (5) and outputs the calculated left-wheel load-ratio WR__l to the individual-wheel ground-load calculating portion 2g, the individual-wheel requested-lateral-force calculating portion 2i, and the individual-wheel lateral-force calculating portion 2j.

$$WR\_l=0.5-((d^2y/dt^2)/G)\cdot(h/L_{tred}) \qquad (5)$$

In this case, L_{tred} indicates an average of respective tread values of the front and rear wheels.

The individual-wheel ground-load calculating portion 2g receives the front-wheel ground load F_{zf} and the rear-wheel ground load F_{zr} from the front-rear ground-load calculating portion 2e, and also receives the left-wheel load-ratio WR__l from the left-wheel load-ratio calculating portion 2f. The individual-wheel ground-load calculating portion 2g calculates a front-left-wheel ground load F_{zf_l}, a front-right-wheel ground load F_{zf_r}, a rear-left-wheel ground load F_{zr_l}, and a rear-right-wheel ground load F_{zr_r} from the following expressions (6), (7), (8), and (9), respectively, and outputs these calculated values to the individual-wheel friction-circle limit-value calculating portion 2k.

$$F_{zf\_l}=F_{zf}\cdot WR\_l \qquad (6)$$

$$F_{zf\_r}=F_{zf}(1-WR\_l) \qquad (7)$$

$$F_{zr\_l}=F_{zr}\cdot WR\_l \qquad (8)$$

$$F_{zr\_r}=F_{zr}\cdot(1-WR\_l) \qquad (9)$$

The individual-wheel longitudinal-force calculating portion 2h receives a tightening torque T_{LSD} of the limited-slip differential clutch in the center differential from the transmission control unit 14, the transmission output torque T_t from the transmission-output-torque calculating portion 2c, the total driving force F_x from the total-driving-force calculating portion 2d, and the front-wheel ground load F_{zf} from the front-rear ground-load calculating portion 2e. In accordance with a procedure to be described hereinafter, the individual-wheel longitudinal-force calculating portion 2h calculates a front-left-wheel longitudinal force F_{xf_l}, a front-right-wheel longitudinal force F_{xf_r}, a rear-left-wheel longitudinal force F_{xr_l}, and a rear-right-wheel longitudinal force F_{xr_r}, and outputs these calculated values to the individual-wheel requested-resultant-tire-force calculating portion 2l and the individual-wheel resultant-tire-force calculating portion 2m.

An example of the procedure for calculating the front-left-wheel longitudinal force F_{xf_l}, the front-right-wheel longitudinal force F_{xf_r}, the rear-left-wheel longitudinal force F_{xr_l}, and the rear-right-wheel longitudinal force F_{xr_r} will be described below.

First, a front-wheel load distribution rate W_{R_f} is calculated from the following expression (10):

$$W_{R\_f}=F_{zf}/W \qquad (10)$$

Then, a minimum front-wheel longitudinal torque T_{fmin} and a maximum front-wheel longitudinal torque T_{fmax} are calculated from the following expressions (11) and (12):

$$T_{fmin}=T_t\cdot R_{f\_cd}-T_{LSD}(\geq 0) \qquad (11)$$

$$T_{fmax}=T_t\cdot R_{f\_cd}+T_{LSD}(\geq 0) \qquad (12)$$

Subsequently, a minimum front-wheel longitudinal force F_{xfmin} and a maximum front-wheel longitudinal force F_{xfmax} are calculated from the following expressions (13) and (14):

$$F_{xfmin}=T_{fmin}\cdot\eta\cdot i_f/R_t \qquad (13)$$

$$F_{xfmax}=T_{fmax}\cdot\eta\cdot i_f/R_t \qquad (14)$$

Next, a determination value I is set in the following manner.

When $W_{R\_f}\leq F_{xfmin}/F_x$, it is determined that limited-slip differential torque is increasing at the rear wheels, thereby setting the determination value I to 1.

When $W_{R\_f}\geq F_{xfmax}/F_x$, it is determined that limited-slip differential torque is increasing at the front wheels, thereby setting the determination value I to 3.

In cases other than the above (i.e. when $F_{xfmin}/F_x<W_{R\_f}<F_{xfmax}/F_x$), a normal condition is confirmed, thereby setting the determination value I to 2.

In accordance with the determination value I, a front-wheel longitudinal force F_{xf} is calculated as follows:

$$\text{When } I=1:F_{xf}=T_{fmin}\cdot\eta\cdot i_f/R_t \qquad (15)$$

$$\text{When } I=2:F_{xf}=F_{xf}=F_x\cdot W_{R\_f} \qquad (16)$$

$$\text{When } I=3:F_{xf}=T_{fmax}\cdot\eta\cdot i_f/R_t \qquad (17)$$

Based on the front-wheel longitudinal force F_{xf} calculated from the expression (15), (16), or (17), a rear-wheel longitudinal force F_{xr} is calculated from the following expression (18):

$$F_{xr}=F_x-F_{xf} \qquad (18)$$

Using the front-wheel longitudinal force F_{xf} and the rear-wheel longitudinal force F_{xr}, the front-left-wheel longitudinal force F_{xf_l}, the front-right-wheel longitudinal force F_{xf_r}, the rear-left-wheel longitudinal force F_{xr_l}, and the rear-right-wheel longitudinal force F_{xr_r} are calculated from the following expressions (19) to (22):

$$F_{xf\_l}=F_{xf}/2 \qquad (19)$$

$$F_{xf\_r}=F_{xf\_l} \qquad (20)$$

$$F_{xr\_l}=F_{xr}/2 \qquad (21)$$

$$F_{xr\_r}=F_{xr\_l} \qquad (22)$$

The calculations of the longitudinal forces of the individual wheels described above in the first embodiment are simply examples, and are appropriately selectable according to the driving method or driving mechanism of the vehicle.

The individual-wheel requested-lateral-force calculating portion 2i receives the lateral acceleration (d^2y/dt^2) from the lateral-acceleration sensor 15, a yaw rate γ from the yaw-rate sensor 16, a steering-wheel angle θ_H from the steering-wheel-angle sensor 17, wheel speeds ω_{fl}, ω_{fr}, ω_{rl}, and ω_{rr} of the four wheels from the wheel-speed sensors 18 for the respective (four) wheels, and the left-wheel load-ratio WR__l from the left-wheel load-ratio calculating portion 2f.

In accordance with a procedure to be described below (i.e. the flow chart shown in FIG. 8), an additional yaw moment $M_z\theta$ is calculated. Based on this additional yaw moment, a requested front-wheel lateral force F_{yf_FF} is calculated from the following expression (23), and a requested rear-wheel lateral force F_{yr_FF} is calculated from the following expression (24). Based on the requested front-wheel lateral force F_{yf_FF} and the requested rear-wheel lateral force F_{yr_FF}, a front-left-wheel requested lateral force $F_{yf\_l\_FF}$, a front-right-wheel requested lateral force $F_{yf\_r\_FF}$, a rear-left-wheel requested lateral force $F_{yr\_l\_FF}$, and a rear-right-wheel requested lateral force $F_{yr\_r\_FF}$ are calculated from the following expressions (25) to (28) and are output to the individual-wheel requested-resultant-tire-force calculating portion 2l.

$$F_{yf\_FF}=M_z\theta/L \qquad (23)$$

$$F_{yr\_FF}=(-I_z\cdot(d\gamma/dt)+m\cdot(d^2y/dt^2)\cdot L_f)/L \qquad (24)$$

In this case, I_z indicates a yaw moment of inertia of the vehicle, and L_f indicates a distance between the front axle and the center of gravity.

$$F_{yf\_l\_FF}=F_{yf\_FF}\cdot WR\_l \tag{25}$$

$$F_{yf\_r\_FF}=F_{yf\_FF}\cdot(1-WR\_l) \tag{26}$$

$$F_{yr\_l\_FF}=F_{yr\_FF}\cdot WR\_l \tag{27}$$

$$F_{yr\_r\_FF}=F_{yr\_FF}\cdot(1-WR\_l) \tag{28}$$

Next, as shown in FIG. **8**, the additional yaw moment $M_z\theta$ is determined. First, a vehicle speed V is calculated in step **S301** (e.g. $V=(\omega_{fl}+\omega_{fr}+\omega_{rl}+\omega_{rr})/4$) and then a lateral-acceleration/steering-wheel-angle gain G_y is calculated in step **S302** using the following expression (29):

$$G_y=(1/(1+A\cdot V^2))\cdot(V^2/L)\cdot(1/n) \tag{29}$$

In this case, A indicates a stability factor, and n indicates a steering gear ratio.

The process then proceeds to step **S303**, which is a step for referring to a map preliminarily set in accordance with a value $(G_y\cdot\theta_H)$ obtained by multiplying the lateral-acceleration/steering-wheel-angle gain G_y by the steering-wheel angle θ_H and the lateral acceleration (d^2y/dt^2) so as to calculate a lateral-acceleration saturation coefficient $K\mu$. Referring to FIG. **9**A, this map used for determining a lateral-acceleration saturation coefficient $K\mu$ is preliminarily set in accordance with a value $(G_y\cdot\theta_H)$ obtained by multiplying the lateral-acceleration/steering-wheel-angle gain G_y by the steering-wheel angle θ_H and the lateral acceleration (d^2y/dt^2), and decreases with increasing lateral acceleration (d^2y/dt^2) in a state where the steering-wheel angle θ_H is greater than or equal to a predetermined value. This implies that when the $G_y\cdot\theta_H$ is a large value, the lateral acceleration (d^2y/dt^2) becomes greater towards a higher μ road, but the lateral acceleration (d^2y/dt^2) is less likely to occur on a low μ road. Consequently, referring to FIG. **9**B, a reference lateral acceleration (d^2yr/dt^2) to be described hereinafter is set to a low value in the case where the vehicle is considered to be on a high μ road based on the $G_y\cdot\theta_H$ being a large value and the lateral acceleration (d^2y/dt^2) being a large value, so that the correction amount with respect to the additional yaw moment $M_z\theta$ is set to a small amount.

In step **S304**, a lateral-acceleration deviation feedback gain K_y is calculated from the following expression (30):

$$K_y=K\theta/G_y \tag{30}$$

In this case, $K\theta$ indicates a steering-angle feedback gain, which is calculated from the following expression (31):

$$K\theta=(L_f\cdot K_f)/n \tag{31}$$

Here, K_f indicates an equivalent cornering power of the front axle.

Specifically, the lateral-acceleration deviation feedback gain K_y is determined from the expression (30) as a target value (maximum value) in view of the case where the additional yaw moment $M_z\theta$ (stationary value) becomes zero in a state where the steering is absolutely ineffective ($\gamma=0$, $(d^2y/dt^2)=0$) on a significantly low μ road.

Subsequently, in step **S305**, a reference lateral acceleration (d^2yr/dt^2) is calculated from the following expression (32):

$$(d^2yr/dt^2)=K\mu\cdot G_y\cdot(1/(1+T_y\cdot s))\cdot\theta_H \tag{32}$$

In this case, s indicates a differential operator, and T_y indicates a first-order-lag time constant of lateral acceleration. This first-order-lag time constant T_y is calculated from, for

example, the following expression (33) with an equivalent cornering power of the rear axle indicated by K_r:

$$T_y=I_z/(L\cdot K_r) \tag{33}$$

In step **S306**, a lateral-acceleration deviation (d^2ye/dt^2) is calculated from the following expression (34):

$$(d^2ye/dt^2)=(d^2y/dt^2)-(d^2yr/dt^2) \tag{34}$$

Subsequently, in step **S307**, a yaw-rate/steering-wheel-angle gain $G\gamma$ is calculated from the following expression (35):

$$G\gamma=(1/(1+A\cdot V^2))\cdot(V/L)\cdot(1/n) \tag{35}$$

In step **S308**, a yaw-rate feedback gain $K\gamma$ is calculated from the following expression (36) in view of the case where, for example, the additional yaw moment $M_z\theta$ (stationary value) becomes zero at the time of grip driving (when $(d^2ye/dt^2)=0$).

$$K\gamma=K\theta/G\gamma \tag{36}$$

In step **S309**, a vehicle-speed feedback gain K_v is calculated on the basis of a preliminarily set map. This map is set so as to avoid an undesired additional yaw moment $M_z\theta$ in a low speed range, as shown in, for example, FIG. **10**. In FIG. **10**, V_{c1} represents, for example, 40 km/h.

In step **S310**, an additional yaw moment $M_z\theta$ is calculated from the following expression (37):

$$M_z\theta=K_v\cdot(-K\gamma\cdot\gamma+K_y\cdot(d^2ye/dt^2)+K\theta\cdot\theta_H) \tag{37}$$

As shown in expression (37), the term $-K\gamma\cdot\gamma$ corresponds to a yaw moment responding to a yaw rate γ, the term $K\theta\cdot\theta_H$ corresponds to a yaw moment responding to a steering-wheel angle θ_H, and the term $K_y\cdot(d^2ye/dt^2)$ corresponds to a correction value of the yaw moment. Therefore, when the vehicle is driven with a large lateral acceleration (d^2y/dt^2) on a high μ road as shown in FIG. **11**, the additional yaw moment $M_z\theta$ also becomes a large value, thereby enhancing the driving performance. On the other hand, when the vehicle is driven on a low μ road, the additional yaw moment $M_z\theta$ is prevented from increasing since the additional yaw moment $M_z\theta$ is reduced due to the effect of the correction value, thereby allowing for stable driving performance.

The individual-wheel lateral-force calculating portion **2j** receives the lateral acceleration (d^2y/dt^2) from the lateral-acceleration sensor **15**, the yaw rate γ from the yaw-rate sensor **16**, and the left-wheel load-ratio WR_l from the left-wheel load-ratio calculating portion **2f**. Then, the individual-wheel lateral-force calculating portion **2j** calculates a front-wheel lateral force F_{yf_FB} and a rear-wheel lateral force F_{yr_FB} from the following expressions (38) and (39), respectively. Based on the front-wheel lateral force F_{yf_FB} and the rear-wheel lateral force F_{yr_FB}, the individual-wheel lateral-force calculating portion **2j** calculates a front-left-wheel lateral force $F_{yf\_l\_FB}$, a front-right-wheel lateral force $F_{yf\_r\_FB}$, a rear-left-wheel lateral force $F_{yr\_l\_FB}$, and a rear-right-wheel lateral force $F_{yr\_r\_FB}$ from the following expressions (40) to (43), and outputs these calculated values to the individual-wheel resultant-tire-force calculating portion **2m**.

$$F_{yf\_FB}=(I_z\cdot(d\gamma/dt)+m\cdot(d^2y/dt^2)\cdot L_r)/L \tag{38}$$

$$F_{yr\_FB}=(-I_z\cdot(d\gamma/dt)+m\cdot(d^2y/dt^2)\cdot L_f)/L \tag{39}$$

Here, L_r indicates a distance between the rear axle and the center of gravity.

$$F_{yf\_l\_FB}=F_{yf\_FB}\cdot WR\_l \tag{40}$$

$$F_{yf\_r\_FB}=F_{yf\_FB}\cdot(1-WR\_l) \tag{41}$$

$$F_{yr\_l\_FB}=F_{yr\_FB}\cdot WR\_l \tag{42}$$

$$F_{yr\_r\_FB}=F_{yr\_FB}\cdot(1-WR\_l) \tag{43}$$

The individual-wheel friction-circle limit-value calculating portion 2k receives a road-surface friction coefficient μ from the road-surface μ estimation unit 20, and the front-left-wheel ground load F_{zf_l}, the front-right-wheel ground load F_{zf_r}, the rear-left-wheel ground load F_{zr_l}, and the rear-right-wheel ground load F_{zr_r} from the individual-wheel ground-load calculating portion 2g.

The individual-wheel friction-circle limit-value calculating portion 2k then calculates a front-left-wheel friction-circle limit-value μ_F_{zfl}, a front-right-wheel friction-circle limit-value μ_F_{zfr}, a rear-left-wheel friction-circle limit-value μ_F_{zrl}, and a rear-right-wheel friction-circle limit-value μ_F_{zrr} from the following expressions (44) to (47), and outputs the calculated values to the individual-wheel requested-excessive-tire-force calculating portion 2n and the individual-wheel excessive-tire-force calculating portion 2o. In other words, the individual-wheel friction-circle limit-value calculating portion 2k is provided as friction-circle limit-value estimating means as a function for estimating a maximum tire force which the tire is capable of exercising against a current road-surface.

$$\mu\_F_{zfl}=\mu\cdot F_{zf\_l} \tag{44}$$

$$\mu\_F_{zfr}=\mu\cdot F_{zf\_r} \tag{45}$$

$$\mu\_F_{zrl}=\mu\cdot F_{zr\_l} \tag{46}$$

$$\mu\_F_{zrr}=\mu\cdot F_{zr\_r} \tag{47}$$

The individual-wheel requested-resultant-tire-force calculating portion 2l receives the front-left-wheel longitudinal force F_{xf_l}, the front-right-wheel longitudinal force F_{xf_r}, the rear-left-wheel longitudinal force F_{xr_l}, and the rear-right-wheel longitudinal force F_{xr_r} from the individual-wheel longitudinal-force calculating portion 2h, and also receives the front-left-wheel requested lateral force. $F_{yf\_l\_FF}$, the front-right-wheel requested lateral force $F_{yf\_r\_FF}$, the rear-left-wheel requested lateral force $F_{yr\_l\_FF}$, and the rear-right-wheel requested lateral force $F_{yr\_r\_FF}$ from the individual-wheel requested-lateral-force calculating portion 2i. The individual-wheel requested-resultant-tire-force calculating portion 2l calculates a front-left-wheel requested resultant tire force F_fl_FF, a front-right-wheel requested resultant tire force F_fr_FF, a rear-left-wheel requested resultant tire force F_rl_FF, and a rear-right-wheel requested resultant tire force F_rr_FF from the following expressions (48) to (51), and outputs these calculated values to the individual-wheel requested-excessive-tire-force calculating portion 2n. In other words, the individual-wheel requested-resultant-tire-force calculating portion 2l is provided as first-tire-force estimating means.

$$F\_fl\_FF=(F_{xf\_l}{}^2+F_{yf\_l\_FF}{}^2)^{1/2} \tag{48}$$

$$F\_fr\_FF=(F_{xf\_r}{}^2+F_{yf\_r\_FF}{}^2)^{1/2} \tag{49}$$

$$F\_rl\_FF=(F_{xr\_l}{}^2+F_{yr\_l\_FF}{}^2)^{1/2} \tag{50}$$

$$F\_rr\_FF=(F_{xr\_r}{}^2+F_{yr\_r\_FF}{}^2)^{1/2} \tag{51}$$

The individual-wheel resultant-tire-force calculating portion 2m receives the front-left-wheel longitudinal force F_{xf_l}, the front-right-wheel longitudinal force F_{xf_r}, the rear-left-wheel longitudinal force F_{xr_l}, and the rear-right-wheel longitudinal force F_{xr_r} from the individual-wheel longitudinal-force calculating portion 2h, and also receives the front-left-

wheel lateral force $F_{yf\_l\_FB}$, the front-right-wheel lateral force $F_{yf\_r\_FB}$, the rear-left-wheel lateral force $F_{yr\_l\_FB}$, and the rear-right-wheel lateral force $F_{yr\_r\_FB}$ from the individual-wheel lateral-force calculating portion 2j. The individual-wheel resultant-tire-force calculating portion 2m calculates a front-left-wheel resultant tire force F_fl_FB, a front-right-wheel resultant tire force F_fr_FB, a rear-left-wheel resultant tire force F_rl_FB, and a rear-right-wheel resultant tire force F_rr_FB from the following expressions (52) to (55), and outputs these calculated values to the individual-wheel excessive-tire-force calculating portion 2o. In other words, the individual-wheel resultant-tire-force calculating portion 2m is provided as second-tire-force estimating means.

$$F\_fl\_FB=(F_{xf\_l}{}^2+F_{yf\_l\_FB}{}^2)^{1/2} \tag{52}$$

$$F\_fr\_FB=(F_{xf\_r}{}^2+F_{yf\_r\_FB}{}^2)^{1/2} \tag{53}$$

$$F\_rl\_FB=(F_{xr\_l}{}^2+F_{yr\_l\_FB}{}^2)^{1/2} \tag{54}$$

$$F\_rr\_FB=(F_{xr\_r}{}^2+F_{yr\_r\_FB}{}^2)^{1/2} \tag{55}$$

The individual-wheel requested-excessive-tire-force calculating portion 2n receives the front-left-wheel friction-circle limit-value μ_F_{zfl}, the front-right-wheel friction-circle limit-value μ_F_{zfr}, the rear-left-wheel friction-circle limit-value μ_F_{zrl}, and the rear-right-wheel friction-circle limit-value μ_F_{zrr} from the individual-wheel friction-circle limit-value calculating portion 2k, and also receives the front-left-wheel requested resultant tire force F_fl_FF, the front-right-wheel requested resultant tire force F_fr_FF, the rear-left-wheel requested resultant tire force F_rl_FF, and the rear-right-wheel requested resultant tire force F_rr_FF from the individual-wheel requested-resultant-tire-force calculating portion 2l. The individual-wheel requested-excessive-tire-force calculating portion 2n then calculates a front-left-wheel requested excessive tire force ΔF_fl_FF, a front-right-wheel requested excessive tire force ΔF_fr_FF, a rear-left-wheel requested excessive tire force ΔF_rl_FF, and a rear-right-wheel requested excessive tire force ΔF_rr_FF from the following expressions (56) to (59), and outputs these calculated values to the excessive-tire-force calculating portion 2p. In other words, the individual-wheel requested-excessive-tire-force calculating portion 2n is provided as first-excessive-tire-force estimating means.

$$\Delta F\_fl\_FF=F\_fl\_FF-\mu\_F_{zfl} \tag{56}$$

$$\Delta F\_fr\_FF=F\_fr\_FF-\mu\_F_{zfr} \tag{57}$$

$$\Delta F\_rl\_FF=F\_rl\_FF-\mu\_F_{zrl} \tag{58}$$

$$\Delta F\_rr\_FF=F\_rr\_FF-\mu\_F_{zrr} \tag{59}$$

The individual-wheel excessive-tire-force calculating portion 2o receives the front-left-wheel friction-circle limit-value μ_F_{zfl}, the front-right-wheel friction-circle limit-value μ_F_{zfr}, the rear-left-wheel friction-circle limit-value μ_F_{zrl}, and the rear-right-wheel friction-circle limit-value μ_F_{zrr} from the individual-wheel friction-circle limit-value calculating portion 2k, and also receives the front-left-wheel resultant tire force F_fl_FB, the front-right-wheel resultant tire force F_fr_FB, the rear-left-wheel resultant tire force F_rl_FB, and the rear-right-wheel resultant tire force F_rr_FB from the individual-wheel resultant-tire-force calculating portion 2m. The individual-wheel excessive-tire-force calculating portion 2o then calculates a front-left-wheel excessive tire force ΔF_fl_FB, a front-right-wheel excessive tire force ΔF_fr_FB, a rear-left-wheel excessive tire force ΔF_rl_FB, and a rear-right-wheel excessive tire force ΔF_rr_FB from the following

expressions (60) to (63), and outputs these calculated values to the excessive-tire-force calculating portion $2p$. In other words, the individual-wheel excessive-tire-force calculating portion $2o$ is provided as second-excessive-tire-force estimating means.

$$\Delta F\_{fl}\_{FB}=F\_{fl}\_{FB}-\mu\_F_{zfl} \tag{60}$$

$$\Delta F\_{fr}\_{FB}=F\_{fr}\_{FB}-\mu\_F_{zfr} \tag{61}$$

$$\Delta F\_{rl}\_{FB}=F\_{rl}\_{FB}-\mu\_F_{zrl} \tag{62}$$

$$\Delta F\_{rr}\_{FB}=F\_{rr}\_{FB}-\mu\_F_{zrr} \tag{63}$$

The excessive-tire-force calculating portion $2p$ receives the front-left-wheel requested excessive tire force ΔF_{fl}_{FF}, the front-right-wheel requested excessive tire force ΔF_{fr}_{FF}, the rear-left-wheel requested excessive tire force ΔF_{rl}_{FF}, and the rear-right-wheel requested excessive tire force ΔF_{rr}_{FF} from the individual-wheel requested-excessive-tire-force calculating portion $2n$, and also receives the front-left-wheel excessive tire force ΔF_{fl}_{FB}, the front-right-wheel excessive tire force ΔF_{fr}_{FB}, the rear-left-wheel excessive tire force ΔF_{rl}_{FB}, and the rear-right-wheel excessive tire force ΔF_{rr}_{FB} from the individual-wheel excessive-tire-force calculating portion $2o$. The excessive-tire-force calculating portion $2p$ then compares a total value of the requested excessive tire forces ΔF_{fl}_{FF}, ΔF_{fr}_{FF}, ΔF_{rl}_{FF}, and ΔF_{rr}_{FF} with a total value of the excessive tire forces ΔF_{fl}_{FB}, ΔF_{fr}_{FB}, ΔF_{rl}_{FB}, and ΔF_{rr}_{FB}, and sets the larger one of the two values as an excessive tire force F_{over}.

$$F_{over}=\text{MAX}((\Delta F\_{fl}\_{FF}+\Delta F\_{fr}\_{FF}+\Delta F\_{rl}\_{FF}+\Delta F\_{rr}\_{FF}),(\Delta F\_{fl}\_{FB}+\Delta F\_{fr}\_{FB}+\Delta F\_{rl}\_{FB}+\Delta F\_{rr}\_{FB})) \tag{64}$$

The over-torque calculating portion $2q$ receives the engine speed N_e from the engine-speed sensor 12, the main transmission gear ratio i and the turbine speed N_t of the torque converter from the transmission control unit 14, and the excessive tire force F_{over} from the excessive-tire-force calculating portion $2p$. The over-torque calculating portion $2q$ calculates an over-torque T_{over} from the following expression (65), and outputs the calculated value to the control-amount calculating portion $2r$.

$$T_{over}=F_{over}\cdot R_t/t/i/\eta/i_f \tag{65}$$

The control-amount calculating portion $2r$ receives the requested engine torque T_{drv} from the requested-engine-torque calculating portion $2b$, and also receives the over-torque T_{over} from the over-torque calculating portion $2q$. The control-amount calculating portion $2r$ calculates a first control amount (=a first torque-down amount) TTCS1 from the following expression (66) and outputs the calculated value to the control-amount setting unit 4.

$$TTCS1=T_{drv}-T_{over} \tag{66}$$

Accordingly, in the first embodiment, the excessive-tire-force calculating portion $2p$, the over-torque calculating portion $2q$, and the control-amount calculating portion $2r$ constitute driving-force setting means that corrects a driving force requested by a driver.

A first control-amount setting program performed by the driving force control device 2 will now be described with reference to the flow charts shown in FIGS. 4 and 5.

In step S201, required parameters are read, which include a throttle opening θ_{th}, an engine speed N_e, an accelerator opening θ_{ACC}, a main transmission gear ratio i, a turbine speed N_t of a torque converter, a tightening torque T_{LSD} of a limited-slip differential clutch, a lateral acceleration (d^{2}y/

dt^2), a yaw rate γ, a steering-wheel angle θ_H, wheel speeds ω_{fl}, ω_{fr}, ω_{rl}, and ω_{rr} of the individual wheels, and a road-surface friction coefficient μ.

In step S202, the engine-torque calculating portion $2a$ refers to a map (such as the map shown in FIG. 6) preliminarily set based on engine characteristics so as to determine an engine torque T_{eg} currently being generated.

In step S203, the requested-engine-torque calculating portion $2b$ determines a throttle opening θ_{th} from a preliminarily set map (such as the map in FIG. 7 showing a relationship between θ_{ACC} and θ_{th}). Based on the throttle opening θ_{th}, the requested-engine-torque calculating portion $2b$ determines an engine torque T_{eg} as a requested engine torque T_{drv} from the aforementioned map in FIG. 6.

In step S204, the transmission-output-torque calculating portion $2c$ calculates a transmission output torque T_t from the aforementioned expression (1).

In step S205, the total-driving-force calculating portion $2d$ calculates a total driving force F_x from the aforementioned expression (2).

In step S206, the front-rear ground-load calculating portion $2e$ calculates a front-wheel ground load F_{zf} from the aforementioned expression (3) and a rear-wheel ground load F_{zr} from the aforementioned expression (4).

In step S207, the left-wheel load-ratio calculating portion $2f$ calculates a left-wheel load-ratio WR_l from the aforementioned expression (5).

In step S208, the individual-wheel ground-load calculating portion $2g$ calculates a front-left-wheel ground load F_{zf_l}, a front-right-wheel ground load F_{zf_r}, a rear-left-wheel ground load F_{zr_l}, and a rear-right-wheel ground load F_{zr_r} from the aforementioned expressions (6), (7), (8), and (9), respectively.

In step S209, the individual-wheel longitudinal-force calculating portion $2h$ calculates a front-left-wheel longitudinal force F_{xf_l}, a front-right-wheel longitudinal force F_{xf_r}, a rear-left-wheel longitudinal force F_{xr_l}, and a rear-right-wheel longitudinal force F_{xr_r} from the aforementioned expressions (19) to (22), respectively. Subsequently, in step S210, the individual-wheel requested-lateral-force calculating portion $2i$ calculates a front-left-wheel requested lateral force $F_{yf\_l\_FF}$, a front-right-wheel requested lateral force $F_{yf\_r\_FF}$, a rear-left-wheel requested lateral force $F_{yr\_l\_FF}$, and a rear-right-wheel requested lateral force $F_{yr\_r\_FF}$ from the aforementioned expressions (25) to (28), respectively.

In step S211, the individual-wheel lateral-force calculating portion $2j$ calculates a front-left-wheel lateral force $F_{yf\_l\_FB}$, a front-right-wheel lateral force $F_{yf\_r\_FB}$, a rear-left-wheel lateral force $F_{yr\_l\_FB}$, and a rear-right-wheel lateral force $F_{yr\_r\_FB}$ from the aforementioned expressions (40) to (43), respectively.

In step S212, the individual-wheel friction-circle limit-value calculating portion $2k$ calculates a front-left-wheel friction-circle limit-value μ_F_{zfl}, a front-right-wheel friction-circle limit-value μ_F_{zfr}, a rear-left-wheel friction-circle limit-value μ_F_{zrl}, and a rear-right-wheel friction-circle limit-value μ_F_{zrr} from the aforementioned expressions (44) to (47), respectively.

In step S213, the individual-wheel requested-resultant-tire-force calculating portion $2l$ calculates a front-left-wheel requested resultant tire force F_{fl}_{FF}, a front-right-wheel requested resultant tire force F_{fr}_{FF}, a rear-left-wheel requested resultant tire force F_{rl}_{FF}, and a rear-right-wheel requested resultant tire force F_{rr}_{FF} from the aforementioned expressions (48) to (51), respectively.

In step S214, the individual-wheel resultant-tire-force calculating portion $2m$ calculates a front-left-wheel resultant tire

force F_{fl}_{FB}, a front-right-wheel resultant tire force F_{fr}_{FB}, a rear-left-wheel resultant tire force F_{rl}_{FB}, and a rear-right-wheel resultant tire force F_{rr}_{FB} from the aforementioned expressions (52) to (55), respectively.

In step **S215**, the individual-wheel requested-excessive-tire-force calculating portion **2n** calculates a front-left-wheel requested excessive tire force ΔF_{fl}_{FF}, a front-right-wheel requested excessive tire force ΔF_{fr}_{FF}, a rear-left-wheel requested excessive tire force ΔF_{rl}_{FF}, and a rear-right-wheel requested excessive tire force ΔF_{rr}_{FF} from the aforementioned expressions (56) to (59), respectively.

In step **S216**, the individual-wheel excessive-tire-force calculating portion **2o** calculates a front-left-wheel excessive tire force ΔF_{fl}_{FB}, a front-right-wheel resultant excessive tire force ΔF_{fr}_{FB}, a rear-left-wheel resultant excessive tire force ΔF_{rl}_{FB}, and a rear-right-wheel resultant excessive tire force ΔF_{rr}_{FB} from the aforementioned expressions (60) to (63), respectively.

In step **S217**, the excessive-tire-force calculating portion **2p** calculates an excessive tire force F_{over} from the aforementioned expression (64).

In step **S218**, the over-torque calculating portion **2q** calculates an over-torque T_{over} from the aforementioned expression (65). In step **S119**, the control-amount calculating portion **2r** calculates a first control amount (=a first torque-down amount) TTCS1 from the aforementioned expression (66) and outputs the calculated value to the control amount setting unit **4**. Finally, this exits the program.

According to the first embodiment of the present invention, in the first traction control unit **2**, a torque value at which a tire force to be generated on each wheel based on a request from the driver exceeds the friction-circle limit value is compared with a torque value at which a tire force currently being generated on the wheel exceeds the friction-circle limit value, and the driving force is corrected by subtracting the larger one of the two values from a driving force requested by the driver. Consequently, an over-torque condition can be appropriately corrected not only for the present but also for the future, whereby appropriate control against spinning and plowing can be implemented. Thus, the grip forces of the tires can be appropriately maintained, whereby the driving stability of the vehicle can be improved.

Since the correction value to be subtracted from the driving force requested by the driver is simply a torque value at which a tire force exceeds the friction-circle limit value, a sudden reduction of the driving force in the longitudinal direction is prevented. This prevents the driver from feeling awkward or from having a sense of dissatisfaction due to a lack of acceleration (i.e. the driving force is inhibited only by an amount F_{xa} in FIG. **12**).

Alternatively, the grip forces of the tires may be maintained by properly inhibiting the driving force in the longitudinal direction (namely, the driving force may be inhibited only by an amount F_{xb} in FIG. **12**). In that case, the control is realized by adding signal lines shown with dashed lines in FIG. **3**, and by changing the calculations performed by the individual-wheel requested-excessive-tire-force calculating portion **2n** and the individual-wheel excessive-tire-force calculating portion **2o** in the following manner.

The individual-wheel requested-excessive-tire-force calculating portion **2n** receives the front-left-wheel friction-circle limit-value μ_F_{zfl}, the front-right-wheel friction-circle limit-value μ_F_{zfr}, the rear-left-wheel friction-circle limit-value μ_F_{zrl}, and the rear-right-wheel friction-circle limit-value μ_F_{zrr} from the individual-wheel friction-circle limit-value calculating portion **2k**, receives the front-left-wheel requested lateral force $F_{yf\_l\_FF}$, the front-right-wheel

requested lateral force $F_{yf\_r\_FF}$, the rear-left-wheel requested lateral force $F_{yr\_l\_FF}$, and the rear-right-wheel requested lateral force $F_{yr\_r\_FF}$ from the individual-wheel requested-lateral-force calculating portion **2i**, and receives the front-left-wheel longitudinal force F_{xf_l}, the front-right-wheel longitudinal force F_{xf_r}, the rear-left-wheel longitudinal force F_{xr_l}, and the rear-right-wheel longitudinal force F_{xr_r} from the individual-wheel longitudinal-force calculating portion **2h**.

The individual-wheel requested-excessive-tire-force calculating portion **2n** calculates a front-left-wheel requested excessive tire force ΔF_{fl}_{FF}, a front-right-wheel requested excessive tire force ΔF_{fr}_{FF}, a rear-left-wheel requested excessive tire force ΔF_{rl}_{FF}, and a rear-right-wheel requested excessive tire force ΔF_{rr}_{FF} from the following expressions (67) to (70), and outputs these calculated values to the excessive-tire-force calculating portion **2p**.

$$\Delta F\_{fl}\_{FF}=F_{xf\_l}-(\mu\_F_{zfl}{}^2-F_{yf\_l\_FF}{}^2)^{1/2} \tag{67}$$

$$\Delta F\_{fr}\_{FF}=F_{xf\_l}-(\mu\_F_{zfr}{}^2-F_{yf\_r\_FF}{}^2)^{1/2} \tag{68}$$

$$\Delta F\_{rl}\_{FF}=F_{xr\_l}-(\mu\_F_{zrl}{}^2-F_{yr\_l\_FF}{}^2)^{1/2} \tag{69}$$

$$\Delta F\_{rr}\_{FF}=F_{xr\_r}-(\mu\_F_{zrr}{}^2-F_{yr\_r\_FF}{}^2)^{1/2} \tag{70}$$

The individual-wheel excessive-tire-force calculating portion **2o** receives the front-left-wheel friction-circle limit-value μ_F_{zfl}, the front-right-wheel friction-circle limit-value μ_F_{zfr}, the rear-left-wheel friction-circle limit-value μ_F_{zrl}, and the rear-right-wheel friction-circle limit-value μ_F_{zrr} from the individual-wheel friction-circle limit-value calculating portion **2k**, receives the front-left-wheel lateral force $F_{yf\_l\_FB}$, the front-right-wheel lateral force $F_{yf\_r\_FB}$, the rear-left-wheel lateral force $F_{yr\_l\_FB}$, and the rear-right-wheel lateral force $F_{yr\_r\_FB}$ from the individual-wheel lateral-force calculating portion **2j**, and receives the front-left-wheel longitudinal force F_{xf_l}, the front-right-wheel longitudinal force F_{xf_r}, the rear-left-wheel longitudinal force F_{xr_l}, and the rear-right-wheel longitudinal force F_{xr_r} from the individual-wheel longitudinal-force calculating portion **2h**.

The individual-wheel excessive-tire-force calculating portion **2o** then calculates a front-left-wheel excessive tire force ΔF_{fl}_{FB}, a front-right-wheel excessive tire force ΔF_{fr}_{FB}, a rear-left-wheel excessive tire force ΔF_{rl}_{FB}, and a rear-right-wheel excessive tire force ΔF_{rr}_{FB} from the following expressions (71) to (74), and outputs these calculated values to the excessive-tire-force calculating portion **2p**.

$$\Delta F\_{fl}\_{FB}=F_{xf\_l}-(\mu\_F_{zfl}{}^2-F_{yf\_l\_FB}{}^2)^{1/2} \tag{71}$$

$$\Delta F\_{fr}\_{FB}=F_{xf\_l}-(\mu\_F_{zfr}{}^2-F_{yf\_r\_FB}{}^2)^{1/2} \tag{72}$$

$$\Delta F\_{rl}\_{FB}=F_{xr\_l}-(\mu\_F_{zrl}{}^2-F_{yr\_l\_FB}{}^2)^{1/2} \tag{73}$$

$$\Delta F\_{rr}\_{FB}=F_{xr\_r}-(\mu\_F_{zrr}{}^2-F_{yr\_r\_FB}{}^2)^{1/2} \tag{74}$$

On the other hand, referring to FIG. **1**, the second traction control unit **3** is provided as second torque-down amount calculating means. The second traction control unit **3** is connected to the throttle-opening sensor **11**, the engine-speed sensor **12**, the transmission control unit **14**, the lateral-acceleration sensor **15**, the four wheel-speed sensors **18**, and the longitudinal-acceleration sensor **19**, and receives therefrom signals indicating a throttle opening θ_{th}, an engine speed N_e, a main transmission gear ratio i, a lateral acceleration (d^2y/dt^2), wheel speeds ω_{fl}, ω_{fr}, ω_{rl}, and ω_{rr} of the individual wheels, and a longitudinal acceleration (d^2x/dt^2).

Referring to FIG. **13**, the second traction control unit **3** mainly includes a vehicle-speed calculating portion **3a**, a

slip-rate calculating portion 3b, a total-grip-force calculating portion 3c, an engine-torque calculating portion 3d, a running-resistance-torque calculating portion 3e, and a second control-amount calculating portion 3f.

The vehicle-speed calculating portion 3a receives the wheel speeds ω_{fl}, ω_{fr}, ω_{rl}, and ω_{rr} of the four wheels from the four respective wheel-speed sensors 18 and calculates an average value of the wheel speeds so as to determine a vehicle speed V ($=(\omega_{fl}+\omega_{fr}+\omega_{rl}+\omega_{rr})/4$). The vehicle-speed calculating portion 3a then outputs the vehicle speed V to the slip-rate calculating portion 3b and the running-resistance-torque calculating portion 3e.

The slip-rate calculating portion 3b receives the wheel speeds ω_{fl}, ω_{fr}, ω_{rl}, and ω_{rr} of the four wheels from the four respective wheel-speed sensors 18, and also receives the vehicle speed V from the vehicle-speed calculating portion 3a. The slip-rate calculating portion 3b then calculates a slip rate of each of the wheels from the following expression (75), and outputs the highest slip rate value as a slip rate λ to the second control-amount calculating portion 3f.

$$\lambda=(\omega-V)/\omega\cdot 100 \qquad (75)$$

In this case, ω represents ω_{fl} to ω_{rr}.

The total-grip-force calculating portion 3c receives the lateral acceleration (d^2y/dt^2) from the lateral-acceleration sensor 15, and also receives the longitudinal acceleration (d^2x/dt^2) from the longitudinal-acceleration sensor 19. The total-grip-force calculating portion 3c then calculates a total grip force TG corresponding to the acceleration of the vehicle body from, for example, the following expression (76), and outputs the calculated value to the second control-amount calculating portion 3f.

$$TG=(K1\cdot(d^2x/dt^2))^2+(K2\cdot(d^2y/dt^2))^2)^{1/2} \qquad (76)$$

In this case, K1 and K2 indicate correction coefficients.

Similar to the engine-torque calculating portion 2a in the first traction control unit 2, the engine-torque calculating portion 3d receives the throttle opening θ_{th} from the throttle-opening sensor 11 and the engine speed N_e from the engine-speed sensor 12. The engine-torque calculating portion 3d refers to a map (such as the map shown in FIG. 6) preliminarily set based on engine characteristics so as to determine an engine torque T_{eg} currently being generated. The engine-torque calculating portion 3d then outputs the determined engine torque T_{eg} to the second control-amount calculating portion 3f. The engine torque T_{eg} may alternatively be read from the engine control unit 5.

The running-resistance-torque calculating portion 3e receives the main transmission gear ratio i from the transmission control unit 14 and the vehicle speed V from the vehicle-speed calculating portion 3a. The running-resistance-torque calculating portion 3e then calculates a running resistance T_p consisting of a rolling resistance of the tires and an air resistance of the vehicle body using, for example, the following expression (77), and outputs the calculated value to the second control-amount calculating portion 3f.

$$T_p=(K3+K4\cdot V^2)\cdot i \qquad (77)$$

In this case, K3 and K4 indicate correction coefficients.

The second control-amount calculating portion 3f receives the main transmission gear ratio i from the transmission control unit 14, the slip rate λ from the slip-rate calculating portion 3b, the total grip force TG from the total-grip-force calculating portion 3c, the engine torque T_{eg} from the engine-torque calculating portion 3d, and the running resistance T_p from the running-resistance-torque calculating portion 3e. Then, the second control-amount calculating portion 3f cal-

culates a second control amount T_{TCS2} used for when reducing the engine output torque, and outputs the calculated value to the control-amount setting unit 4.

In detail, based on the following expression (78), a value given filtering of a first-order time lag with respect to the engine torque T_{eg} is calculated as a first initially required engine torque T_{EF}.

$$T_{EF}=(1-K)\cdot T_{EF}(k-1)+K\cdot T_{eg}(k) \qquad (78)$$

Furthermore, a basic initially required torque T_{ii} is retrieved from a preliminarily set map on the basis of the main transmission gear ratio i and the total grip force TG. The basic initially required torque T_{ii} and the running resistance T_p are added together so as to determine a second initially required engine torque T_{ED}.

$$T_{ED}=T_{ii}+T_p \qquad (79)$$

A second initially required engine torque T_{ED} is a sum of the basic initially required torque T_{ii}, which is a torque transmitted to the road surface without being consumed by excessive slipping of the drive wheels, and the running resistance T_p consisting of a rolling resistance of the tires and an air resistance of the vehicle body. Therefore, a second initially required engine torque T_{ED} corresponds to a value obtained by subtracting an ineffective torque consumed by excessive slipping of the drive wheels from the current engine torque T_{eg}.

As will be mentioned in a second control amount calculation program to be described hereinafter, when the slip rate λ exceeds predetermined threshold values L_{C1} and L_{C2}, either the first initially required engine torque T_{EF} or the second initially required engine torque T_{ED} is selected and set as a second control amount (=a second torque-down amount) T_{TCS2}, and is output to the control-amount setting unit 4. On the other hand, if the slip rate λ does not exceed the predetermined threshold values L_{C1} and L_{C2}, the second control amount T_{TCS2} is set to the current engine torque T_{eg} since torque-down in this case is not implemented.

Specifically, the flow chart shown in FIG. 14 illustrates a second control amount calculation program. In step S401, if the slip rate λ is less than or equal to the first threshold value L_{C1}, namely, while the slip rate λ is extremely small and the engine output torque is sufficiently transmitted to the road surface, the operation proceeds to step S402 where the second control amount T_{TCS2} remains to be set at the current engine torque T_{eg} and torque-down control is not implemented.

On the other hand, if the slip rate λ exceeds the first threshold value L_{C1} in step S401 and if the slip rate λ is less than or equal to the second threshold value L_{C2}, which is greater than the first threshold value L_{C1}, in step S403, namely, in a range where the slip rate λ is relatively small, the operation proceeds to step S404 where a first initially required engine torque T_{EF} determined by filtering the engine torque T_{eg} is set as the second control amount T_{TCS2}. By setting the first initially required engine torque T_{EF} and starting feedback control in this manner, a sudden change in the engine torque T_{eg} can be prevented, thereby avoiding an adverse effect on the vehicle behavior. In addition, by using a first initially required engine torque T_{EF} determined by filtering the engine torque T_{eg}, a time lag that occurs until the engine torque T_{eg} converges to a desired value can be compensated for, thereby achieving enhanced feedback properties.

In step S403, if the slip rate λ exceeds the second threshold value L_{C2}, namely, when the slip rate λ is large, the operation proceeds to step S405 where a second initially required engine torque T_{ED}, which is a sum of the basic initially required torque T_{ii} and the running resistance T_p, is set as the

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second control amount T_{TCS2}. As a result, feedback control starts from a maximum initial torque at which the vehicle can possibly be accelerated without an occurrence of excessive slipping of the drive wheels. Consequently, excessive slipping can be made to quickly converge without having a significant effect on the vehicle behavior.

Referring to FIG. **1**, the control-amount setting unit **4** is provided as driving-force setting means, and receives the first control amount (=the first torque-down amount) T_{TCS1} from the first traction control unit **2** and the second control amount (=the second torque-down amount) T_{TCS2} from the second traction control unit **3**. The control-amount setting unit **4** then compares the first control amount T_{TCS1} with the second control amount T_{TCS2} and sets the smaller value (i.e. the value with a larger torque-down amount) as a control amount (=torque-down amount) T_{TCS} to be used by the driving force control device **1**. Subsequently, the control-amount setting unit **4** outputs the control amount T_{TCS} to the engine control unit **5**. Upon receiving a signal indicating the control amount T_{TCS} from the driving force control device **1**, the engine control unit **5** performs control so as to limit the driving force to an amount less than or equal to the control amount T_{TCS}.

Specifically, referring to FIG. **2**, the driving force control device **1** performs a driving force control program. In step **S101**, the first traction control unit **2** calculates a first control amount T_{TCS1}. In step **S102**, the second traction control unit **3** calculates a second control amount T_{TCS2}.

In step **S103**, the first control amount T_{TCS1} and the second control amount T_{TCS2} are compared. If the first control amount T_{TCS1} is less than or equal to the second control amount T_{TCS2}, the operation proceeds to step **S104** where the first control amount T_{TCS1} is set as the control amount T_{TCS}. In contrast, if the first control amount T_{TCS1} is greater than the second control amount T_{TCS2}, the operation proceeds to step **S105** where the second control amount T_{TCS2} is set as the control amount T_{TCS}.

Subsequently, in step **S106**, the control amount T_{TCS} set in step **S104** or **S105** is output to the engine control unit **5**. Finally, this exits the program.

According to this embodiment, the first traction control unit **2** is provided, which is configured to estimate a tire force generated on a tire and to estimate a friction-circle limit as a maximum tire force which the tire is capable of exercising against a current road-surface and to calculate a first torque-down amount on the basis of a relation between the tire force and the friction-circle limit-value, and the second traction control unit **3** is provided, which is configured to calculate a slip rate of the tire and calculate a second torque-down amount on the basis of at least the slip rate. The control-amount setting unit **4** compares the first torque-down amount T_{TCS1} with the second torque-down amount T_{TCS2} and sets the smaller value (i.e. the value with a larger torque-down amount) as a control amount T_{TCS} to be used by the driving force control device **1**. The control-amount setting unit **4** then outputs the control amount T_{TCS} to the engine control unit **5**.

Accordingly, in a running condition where it is difficult to estimate a friction coefficient μ between the tires and the road surface, such as when the vehicle is in a straight running mode or a starting mode, or in a running condition where the grip forces of the tires in the lateral direction are not very necessary in view of the safety of the vehicle, the grip forces of the tires in the driving direction can be sufficiently used up by means of the second traction control unit **3** that detects the slip rate of the tires and limits the driving torque. On the other hand, in a running condition where the friction coefficient μ between the tires and the road surface can be estimated with high precision, such as when the vehicle is in a cornering

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mode, the slipping of the tires can be prevented from occurring by feed forward control of the driving torque performed by the first traction control unit **2**. Thus, the grip forces of the tires in the lateral direction can be maintained at a high level, thereby enhancing the stability of the vehicle. For example, when the vehicle switches from a cornering mode to a straight running mode or a starting mode, or vice versa, the larger torque-down amount is set as a control amount. Thus, the vehicle can smoothly switch modes without a sudden change in the control amount, thereby achieving control that gives a natural operational feel to the driver.

What is claimed is:

1. A vehicle driving force control device comprising:
   friction-circle limit-value estimating means configured to estimate a friction-circle limit-value as a maximum tire force which the tire is capable of exercising against a current road-surface based on an estimated tire force generated on a tire;
   slip rate calculating means configured to calculate a slip rate of the tire;
   first torque-down amount calculating means configured to calculate a first torque-down amount, as a first torque reduction amount in a state in which the tire is prevented from slipping, on the basis of a relation between the tire force and the friction-circle limit-value;
   second torque-down amount calculating means configured to calculate a second torque-down amount, as a second torque reduction amount in a state in which the tire is slipping, on the basis of at least the slip rate; and
   driving-force setting means configured to set a driving force of the vehicle by reducing a current torque in accordance with one of the first torque-down amount and the second torque-down amount.

2. The vehicle driving force control device according to claim **1**, further comprising:
   road-surface friction coefficient estimating means configured to estimate a road-surface friction coefficient of the current road surface;
   ground-load estimating means configured to estimate a ground-load acting on the tire; wherein the friction-circle limit-value estimating means estimates the friction-circle limit-value on the basis of the road-surface friction coefficient and the ground-load.

3. The vehicle driving force control device according to claim **1**, wherein a tire force estimating means estimates either or both of a first tire force output from an engine to the tire and a second tire force currently generated between the tire and the road-surface as the tire force.

4. The vehicle driving force control device according to claim **2**, wherein a tire force estimating means estimates either or both of a first tire force output from an engine to the tire and a second tire force currently generated between the tire and the road-surface as the tire force.

5. A vehicle driving force control device comprising:
   tire force estimating means configured to estimate a tire force generated on a tire;
   friction-circle limit-value estimating means configured to estimate a friction-circle limit-value as a maximum tire force which the tire is capable of exercising against a current road-surface based on an estimated tire force generated on a tire;
   slip rate calculating means configured to calculate a slip rate of the tire;
   first torque-down amount calculating means configured to calculate a first torque-down amount, as a first torque reduction amount in a state in which the tire is prevented

from slipping, on the basis of a relation between the tire force and the friction-circle limit-value;

second torque-down amount calculating means configured to calculate a second torque-down amount, as a second torque reduction amount in a state in which the tire is slipping, on the basis of at least the slip rate; and

driving-force setting means configured to set a driving force of the vehicle by reducing a current toque in accordance with one of the first torque-down amount and the second torque-down amount;

wherein the tire force estimating means estimates either or both of a first tire force output from an engine to the tire and a second tire force currently generated between the tire and the road-surface as the tire force, and

wherein the first torque-down amount calculating means is configured to calculate a first torque-down amount based on:

a first excessive tire force estimating portion configured to estimate a tire force exceeding the friction-circle limit value on the basis of the first tire force and the friction-circle limit value as a first excessive tire force;

a second excessive tire force estimating portion configured to estimate a tire force exceeding the friction-circle limit value on the basis of the second tire force and the friction-circle limit value as a second excessive tire force; and

a first torque-down amount setting portion configured to set the first torque-down amount on the basis of the first excessive tire force and the second excessive tire force.

6. The vehicle driving force control device according to claim 4,

wherein the first torque-down amount calculating means is configured to calculate a first torque-down amount based on:

a first excessive tire force estimating portion configured to estimate a tire force exceeding the friction-circle limit value on the basis of the first tire force and the friction-circle limit value as a first excessive tire force;

a second excessive tire force estimating portion configured to estimate a tire force exceeding the friction-circle limit value on the basis of the second tire force and the friction-circle limit value as a second excessive tire force; and

a first torque-down amount setting portion configured to set the first torque-down amount on the basis of the first excessive tire force and the second excessive tire force.

7. The vehicle driving force control device according to claim 5, wherein the first torque-down amount setting portion sets the first torque-down amount on the basis of the larger one of the first and second excessive-tire forces.

8. The vehicle driving force control device according to claim 6, wherein the first torque-down amount setting portion sets the first torque-down amount on the basis of the larger one of the first and second excessive-tire forces.

9. The vehicle driving force control device according to claim 1, wherein the driving-force setting means compares the first torque-down amount with the second torque-down amount and limits the driving force by reducing a current torque by the greater of the two torque-down amounts.

10. The vehicle driving force control device according to claim 2, wherein the driving-force setting means compares the first torque-down amount with the second torque-down amount and limits the driving force by reducing a current torque by the greater of the two torque-down amounts.

11. The vehicle driving force control device according to claim 3, wherein the driving-force setting means compares the first torque-down amount with the second torque-down amount and limits the driving force by reducing a current torque by the greater of the two torque-down amounts.

12. The vehicle driving force control device according to claim 4, wherein the driving-force setting means compares the first torque-down amount with the second torque-down amount and limits the driving force by reducing a current torque by the greater of the two torque-down amounts.

13. The vehicle driving force control device according to claim 5, wherein the driving-force setting means compares the first torque-down amount with the second torque-down amount and limits the driving force by reducing a current torque by the greater of the two torque-down amounts.

14. The vehicle driving force control device according to claim 6, wherein the driving-force setting means compares the first torque-down amount with the second torque-down amount and limits the driving force by reducing a current torque by the greater of the two torque-down amounts.

15. The vehicle driving force control device according to claim 7, wherein the driving-force setting means compares the first torque-down amount with the second torque-down amount and limits the driving force by reducing a current torque by the greater of the two torque-down amounts.

16. The vehicle driving force control device according to claim 8, wherein the driving-force setting means compares the first torque-down amount with the second torque-down amount and limits the driving force by reducing a current torque by the greater of the two torque-down amounts.

17. A vehicle driving force control device comprising:

a first traction control unit configured to calculate a first torque control amount, as a first reduced torque amount in a state in which the tire is prevented from slipping, on the basis of at least a relation between a tire force and a friction-circle limit-value, said first traction control unit comprising,

a friction-circle limit-value estimating unit configured to estimate a friction-circle limit-value as a maximum tire force which the tire is capable of exercising against a current road-surface based on an estimated tire force generated on a tire;

a second traction control unit configured to calculate a second torque control amount, as a second reduced torque amount in a state in which the tire is slipping, on the basis of at least a slip rate, said second traction control unit comprising,

a slip rate calculating unit configured to calculate a slip rate of the tire; and

a driving-force setting unit configured to set a driving force for the vehicle by reducing a current torque amount to one of the first torque control amount and the second torque control amount.

18. The vehicle driving force control device according to claim 17, wherein said first traction control unit further comprises an excessive-tire-force calculating portion which sets as an excessive-tire-force amount the larger of a torque value at which a tire-force is requested to be generated, and a torque value at which a tire-force is currently being generated.

19. The vehicle driving force control device according to claim 18, wherein said first traction control unit further comprises an over-torque calculating portion which outputs an over-torque correction value based on the excessive-tire-force amount set by said excessive-tire-force calculating portion.

20. The vehicle driving force control device according to claim 17, wherein, said second traction control unit is con-

figured to set the second torque control amount to be equal to the current engine torque when said slip rate calculating unit calculates the slip rate to be at a value below a predetermined threshold value.

21. The vehicle driving force control device according to claim **1**, wherein

the friction-circle limit-value estimating means is configured to receive a road-surface friction coefficient value from a road surface estimation unit, and wherein

the friction-circle limit-value estimating means is configured to calculate a friction-circle limit-value and output the calculated friction-circle limit-value for use in setting the driving force determined by said driving-force setting means.

22. The vehicle driving force control device according to claim **21** wherein the friction-circle limit-value estimating means estimates a friction-circle limit-value as a maximum tire force which the tire is capable of exercising against a current road-surface through the combined use of at least the road-surface friction coefficient value and a vertical axis wheel ground load input.

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